BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B70 07084

SUBJECT: An Analysis of Navigation Performance for the Subsatellite Experiment
Case 310

DATE: July 28, 1970

FROM: M. V. Bullock
A. J. Ferrari

ABSTRACT

The feasibility of using both a conventional orbit determination technique with the L-1 gravity field and the Osculating Lunar Elements Program (OLEP) to provide ephemeris data for the subsatellite experiment has been studied. Evaluation of Doppler residuals and of dispersions in latitude, longitude, and altitude are presented.

Within the limits of the data used in this study, both techniques satisfy the 3σ accuracy requirements. Analysis shows that most L-1 solutions are not possible without a precise a priori knowledge of the orbit plane. Comparison indicates that OLEP provides more accuracy, has fewer potential problems, and uses less computer time.

(NASA-CR-109969) AN ANALYSIS OF NAVIGATION PERFORMANCE FOR THE SUBSATELLITE EXPERIMENT (Bellcomm, Inc.) 26 p

N79-71837

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(CATEGORY) [redacted]

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MEMORANDUM FOR FILE

1.0 INTRODUCTION

The subsatellite experiments planned for Apollo 16 and 18 require support in the form of ephemeris data at 10-minute intervals during the time of operation. Tracking by MSFN/DSN will be limited to one front side pass per day, with two station coverage planned for twice a week and single station coverage for the remainder.[1] Such a short tracking interval and lack of optimum station geometry pose special problems for orbit determination and prediction techniques.

Solutions obtained from a conventional orbit determination program using the L-1 lunar gravity field and from the Osculating Lunar Elements Program [2] (OLEP) under conditions comparable to those described above are investigated. Evaluations are made in terms of the Doppler range difference residuals and of position deviations in spherical coordinates.

2.0 DATA PROCESSING

Two processing modes are available to generate subsatellite ephemeris information for a one day interval. First, a fit can be obtained from one pass of tracking data and predictions made until the next pass a day later. Second, a fit can be obtained from two passes, a day apart, and interpolations made for the time in between. Since a second tracking station will be used twice a week, the effect of this additional information must also be considered for both modes.

Orbit determinations were performed using Apollo 11 tracking data from lunar orbit front side passes 16 and 25 (post-DOI) to approximate a one day interval for the subsatellite. (This is the longest available period of multi-tracking station, minimum thrusting data.) The table below lists the fit results from both orbit determination techniques.

Number of Passes	Number of Stations	L-1 Solution	OLEP Solution
1	1	Converged only with constrained plane	*NA
1	2	Converged	*NA
2	1/1	Converged only with constrained plane	Converged only with constrained inclination
2	2/1	Converged only with constrained plane	Converged
2	1/2	Converged only with constrained plane	Converged

2.1 L-1 Processing

Fit and prediction Doppler residuals from the converged L-1 solutions are shown in Figures 1 and 2. In the one pass/one station case convergence could only be attained when the out-of-plane parameters were constrained to good initial values. Even though the solution converged, the large residual growth in the prediction region makes this case unusable. The data from an additional station provides the only six degree of freedom solution attainable using the L-1 field.

The two pass processing results (Figure 2) show some improvement over the one pass case, with a lower peak-to-peak amplitude in the residuals and a smaller mean. Convergence could not be obtained without eliminating the out-of-plane parameters from the solution set.

An attempt was made to obtain a two pass solution from an initial state with a slightly incorrect plane. The constrained plane technique was used since no two pass solutions have been attained without it. It was found that constraining the plane to an offset value prohibited convergence.

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*Single pass processing using the OLEP technique produces a solution with poor prediction qualities.

2.2 OLEP Processing

Fit and prediction characteristics of the converged OLEP solutions are shown in the residuals in Figure 3. Two cases are considered: one in which there are three tracking stations, two in the initial pass and one in the final pass, and one in which there are two tracking stations, one per pass. The three station solution was obtained with the following parameter set:

$$\{e_{so}, e_{s1}, e_{co}, e_{c1}, I_o, \Omega_o, \Omega_1, m_o, m_1\}$$

where the low-eccentricity orbital elements ($a, e_s = e \sin \omega$, $e_c = e \cos \omega$, I, Ω, $m = M + \omega$) have been used, with a typical element being represented as

$$\Omega(t) = \Omega_o + \Omega_1 t$$

The inclination rate parameter I_1 was excluded from the solution set because it became highly correlated with other parameters. The residuals from three station processing have a reasonably small peak-to-peak amplitude and display only a slight growth from fit to prediction regions.

An attempt to include the inclination parameter I_o in the solution set for two station processing resulted in divergence. When the inclination was constrained to its initial value, convergence was achieved. The residuals in the prediction region do not differ appreciably from those obtained from the three station solutions. Unlike the case of the L-1 processing, a converged solution was also obtained from an initial state with an offset value of the orbital inclination.

3.0 NAVIGATION ANALYSIS

The solutions presented in the previous section were analyzed for navigation performance by comparing them with local solutions. L-1 solutions were compared with L-1 RTCC single pass solutions. OLEP solutions obtained from processing two consecutive passes of data formed the basis of comparison for the OLEP solutions presented in this study. Differences in selenographic longitude, latitude, and altitude were formed in order to analyze the prediction quality of each solution.

3.1 L-1 Comparisons

Latitude, longitude, and altitude differences for the L-1 solutions are presented in Figures 4a-c. The one pass solution (Figure 4a) gives growing deviations in longitude and altitude, a reflection of differences in in-plane parameters. The decreasing latitude dispersions result from having a poor local solution at the beginning of the comparison interval. The tracking stations available for pass 16 were not sufficiently separated in the north-south direction to provide distinctly different information, particularly about the orbital plane. This bad station geometry resulted in an overabundance of essentially redundant data which corrupted the solution. It is felt that the two station solution presented here is more representative of the true plane than the local (RTCC) solution since the two station solution does not include so much redundant data.

The two pass deviations (Figures 4b and 4c) show a slight improvement over the one pass results. The decreased altitude differences at the center of the interval indicate that the two pass solution obtained good mean values of the semi-major axis and eccentricity. It can be seen that a second station in the first pass (Figure 4c) makes no real difference in the results. In all cases the latitude (out-of-plane) dispersions are the largest.

3.2 OLEP Comparisons

Deviations in latitude, longitude, and altitude for OLEP solutions are shown in Figures 5a-b. The results of the solution in which there were two tracking stations in the initial pass (Figure 5a) show consistency in that there is some growth in all three coordinates through the interval. As in the L-1 comparisons, the latitude dispersions have the largest magnitude. A solution was also made in which the data in the final pass was weighted twice as heavily as the data in the initial pass. The resulting dispersions were unchanged from those in which equal weighting was employed. The constrained inclination solution (Figure 5b) possesses prediction characteristics that are essentially the same as those for the unconstrained case presented above.

3.3 Discussion of Requirements

The required 3σ accuracies for the subsatellite ephemeris are ±2.7 nautical miles (16,420 feet) in altitude and ±8.7 nautical miles in latitude and longitude. The arc equivalent of 8.7 miles is 0.5 degrees. All of the solutions presented in this section fall well within these bounds, with the in-plane OLEP dispersions an order of magnitude smaller than the L-1 dispersions and the out-of-plane dispersions of the same size.

4.0 DISCUSSION

The planned tracking coverage for a given week can be represented in terms of stations per day as

2	1	1	2	1	1	1

The three day span of one station coverage is a potential source of problems for both processing methods.

All L-1 results obtained thus far indicate that only a two station/one pass solution can be obtained in an unconstrained plane mode. For days having one station coverage there are two alternatives. The two station/one pass solution will have to be propagated through the interval to provide all the ephemeris information, or the plane from the two station/one pass solution will have to be accurate enough to be used for two pass constrained plane solutions. Lack of a sufficiently long span of tracking data precludes studying the efficacy of either approach.

Since OLEP cannot be used in a single pass mode, it must rely on two and three pass processing. During the span of one station coverage the ephemeris can be obtained by predictions made from a two pass solution. The question of whether three pass solutions will converge cannot be answered at this time, but on the strength of the low amplitude of the two pass residuals it is felt that three pass processing is feasible.

The factor that distinguishes most clearly between the two processing methods is dependence on planar knowledge. The dependence of the L-1 solutions on a good orbital plane imposes a definite limitation on their usefulness. OLEP, on the other hand, does not need accurate plane information for convergence. Part of the improvement for OLEP can be explained by the fact that its plane constraining can be confined to the inclination parameter, whereas the conventional technique must constrain both the inclination and the longitude of the ascending node.

The number of iterations necessary to attain convergence and the amount of computer time involved varied widely among the various converged solutions. OLEP two pass processing converged after four iterations and 1.5 minutes of computer time. L-1 one pass processing took six iterations and 2.5 minutes, while two pass results required 12 iterations and 13.5 minutes.

5.0 CONCLUSIONS

For the data interval considered in this study, both OLEP and the conventional orbit determination technique yield solutions that are accurate enough to provide ephemeris information for the subsatellite. Deviations in latitude, longitude, and altitude are smaller than the 3σ accuracy requirements. The OLEP approach is preferable for two reasons. First, the heavy dependence of the conventional technique on an accurate plane makes it more susceptible to poor solutions or divergence. Second, the computer time involved with OLEP solutions is significantly lower than that for standard solutions.

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Attachments

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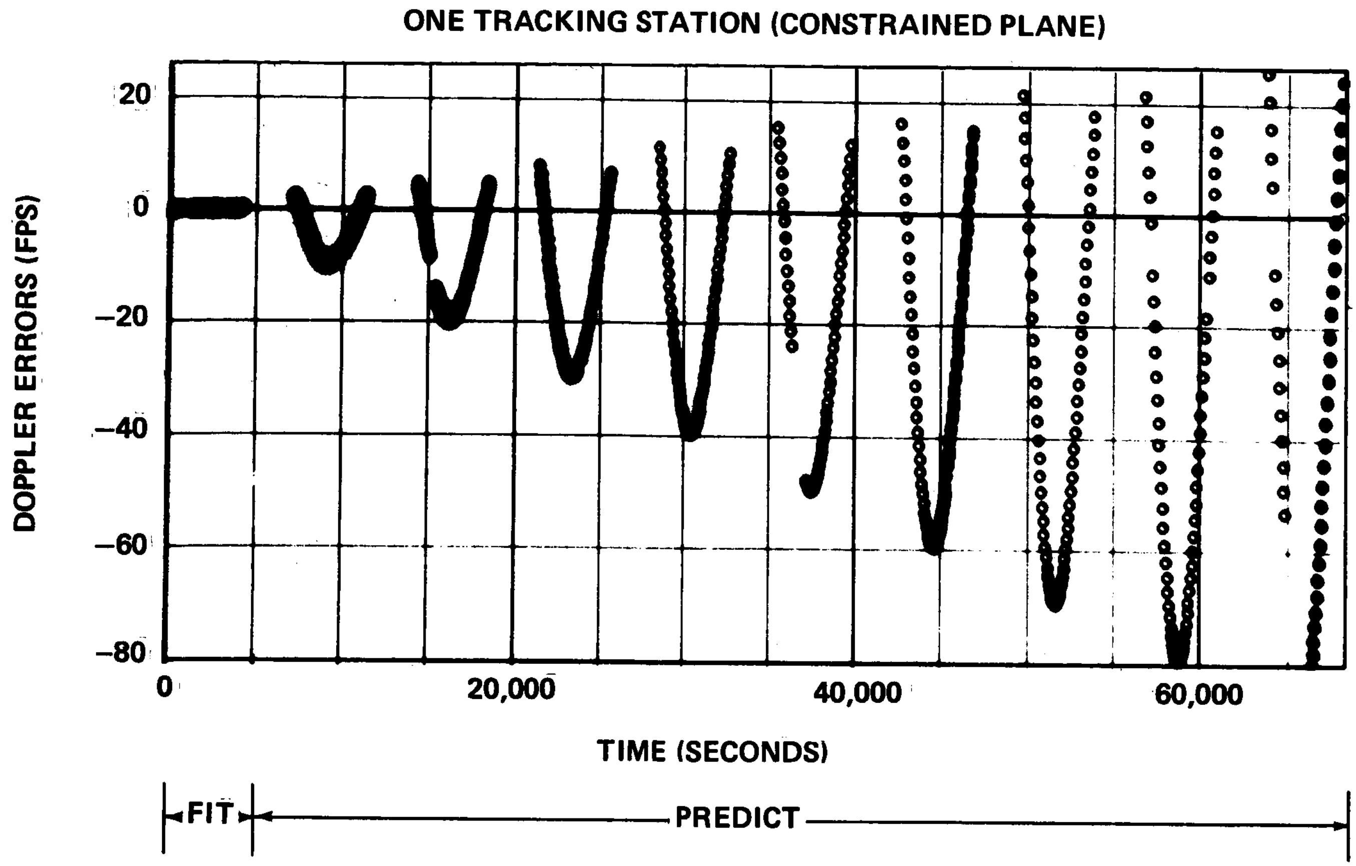
1. McPherson, G. J., "Sixth FOP Lunar Orbital Science Subpanel Meeting at the MSC on June 4, 1970," Bellcomm Memorandum for File, B70 06045, Case 320, June 16, 1970.

2. Bullock, M. V., and Ferrari, A. J., "Orbit Determination for Lunar Parking Orbits Using Time-Varying Orbital Elements," Bellcomm Technical Report TR-70-310-2, May 7, 1970.



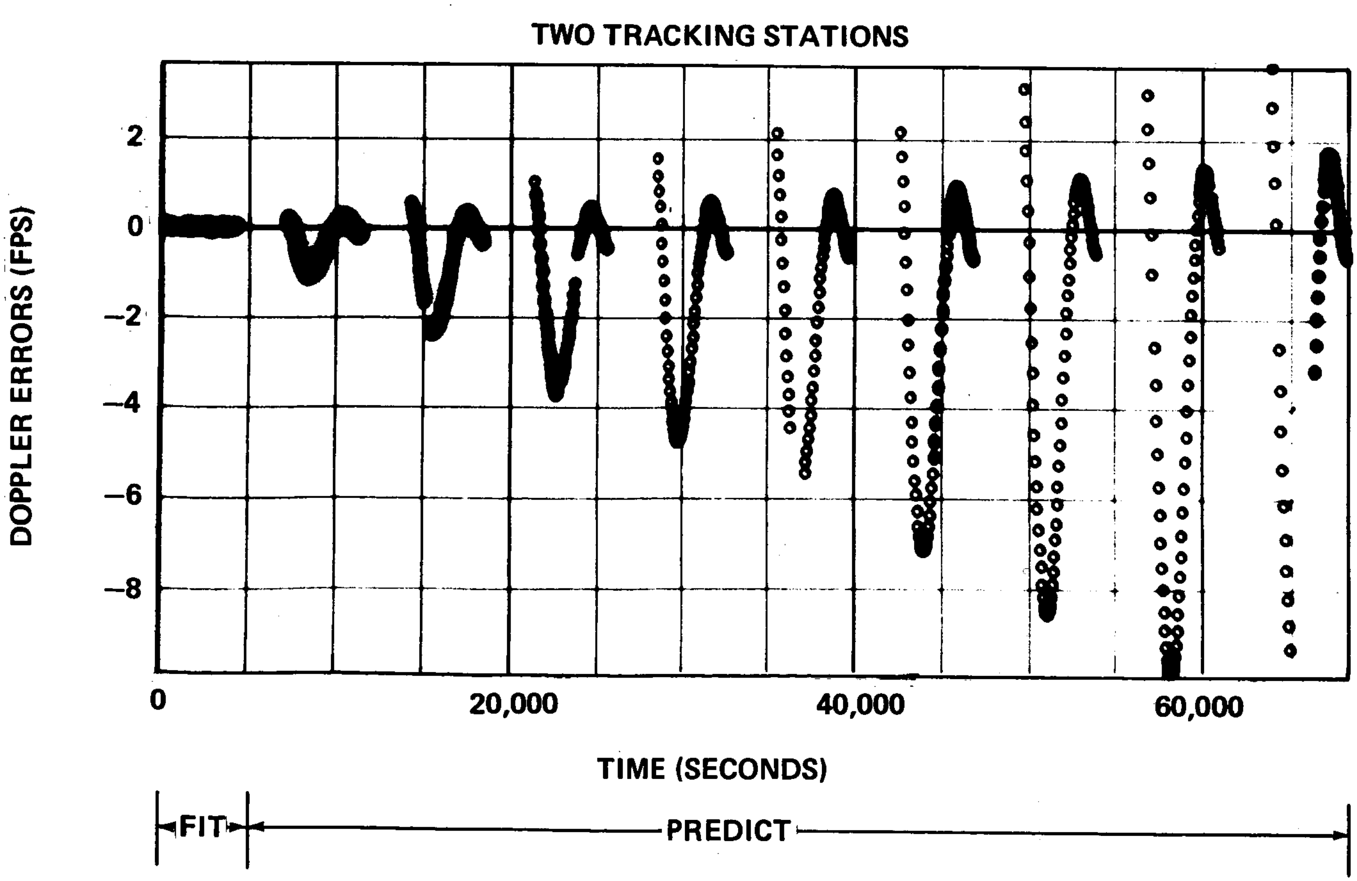


FIGURE 1 - DOPPLER RESIDUALS FROM ONE PASS STANDARD PROCESSING

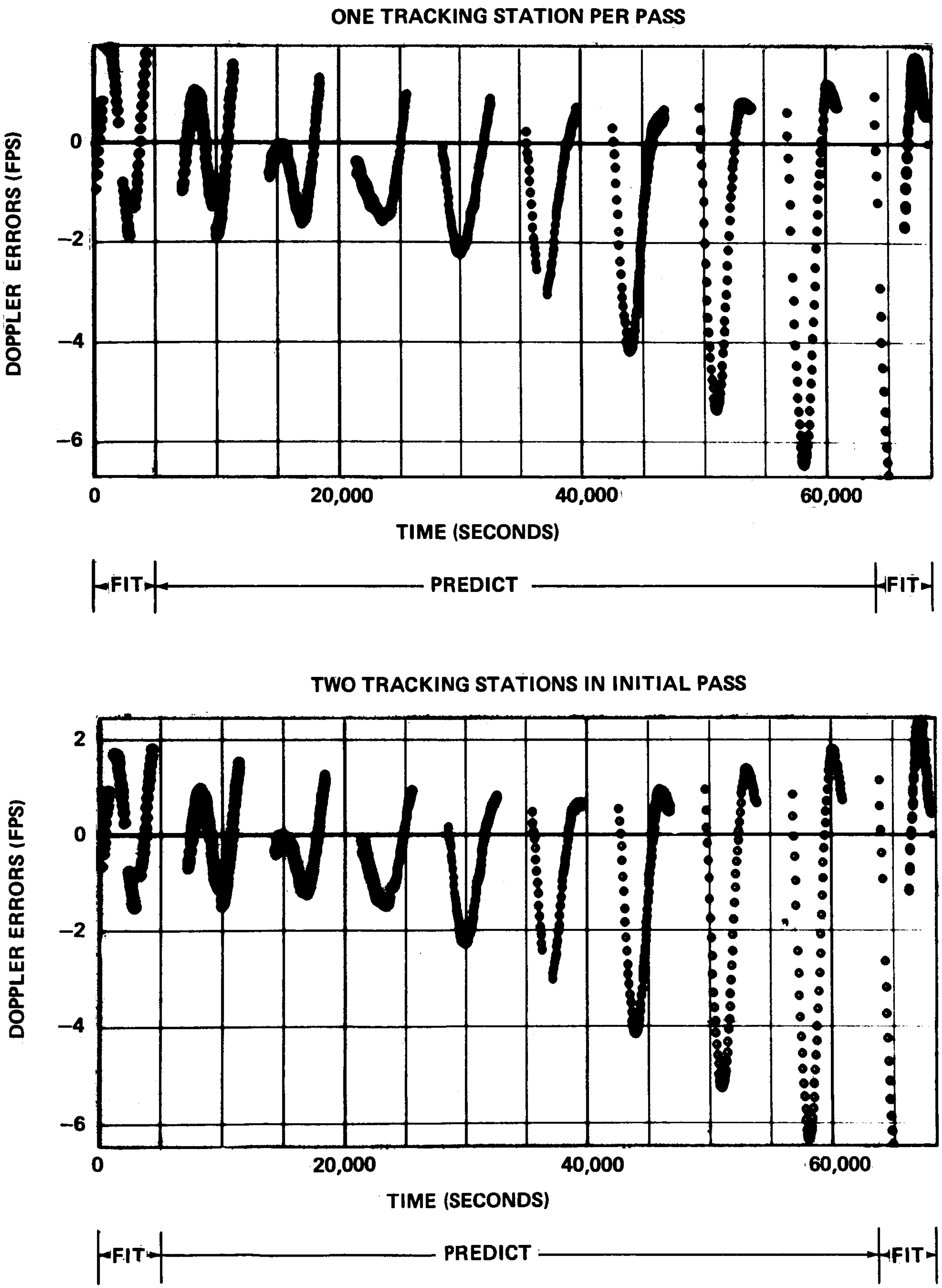
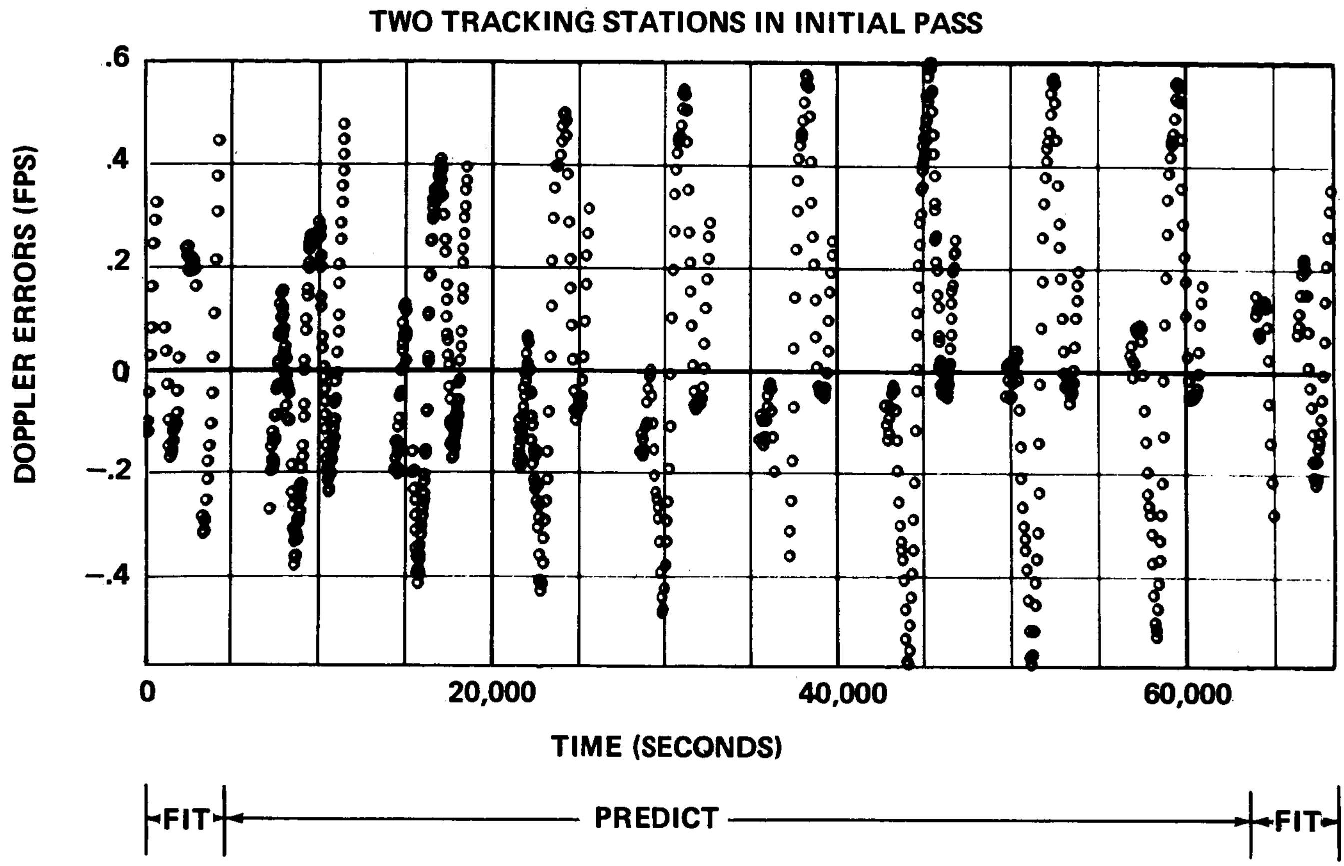


FIGURE 2 - DOPPLER RESIDUALS FROM TWO PASS STANDARD PROCESSING WITH CONSTRAINED PLANE



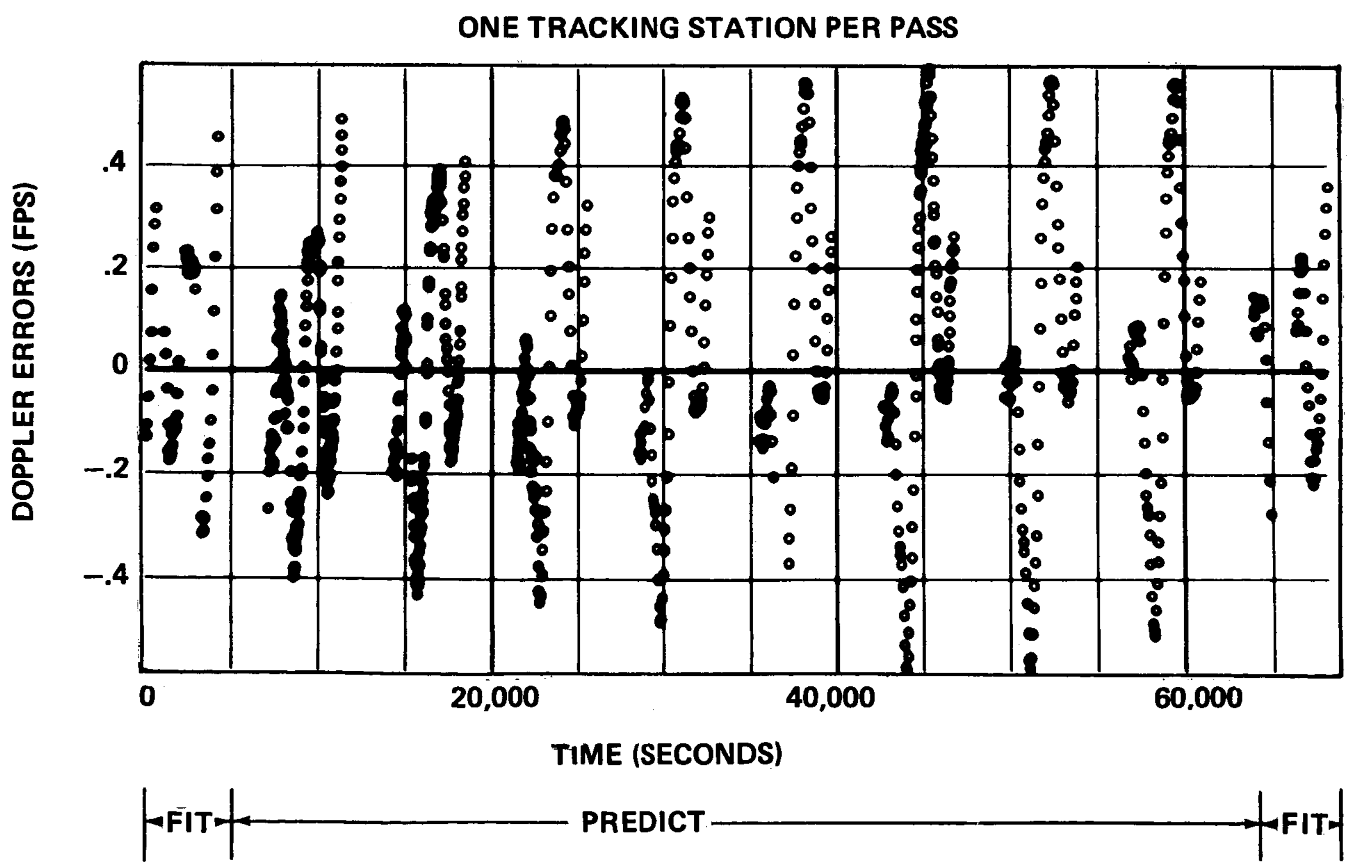
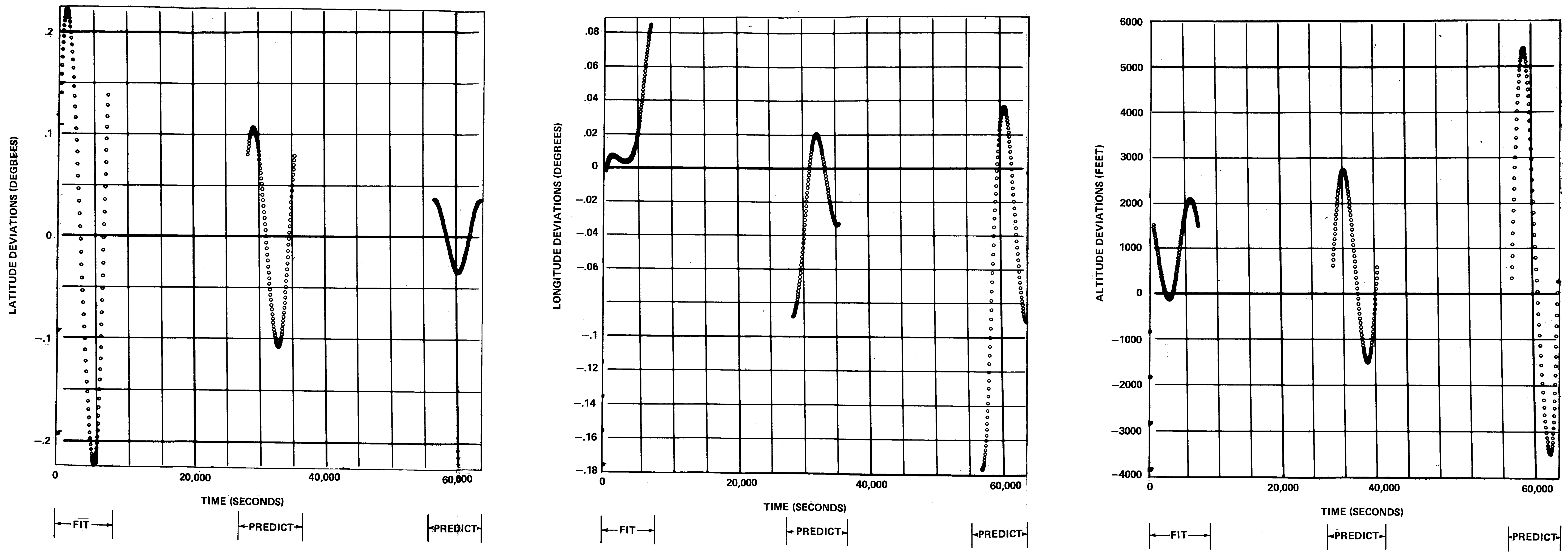


FIGURE 3 - DOPPLER RESIDUALS FROM TWO PASS OLEP PROCESSING



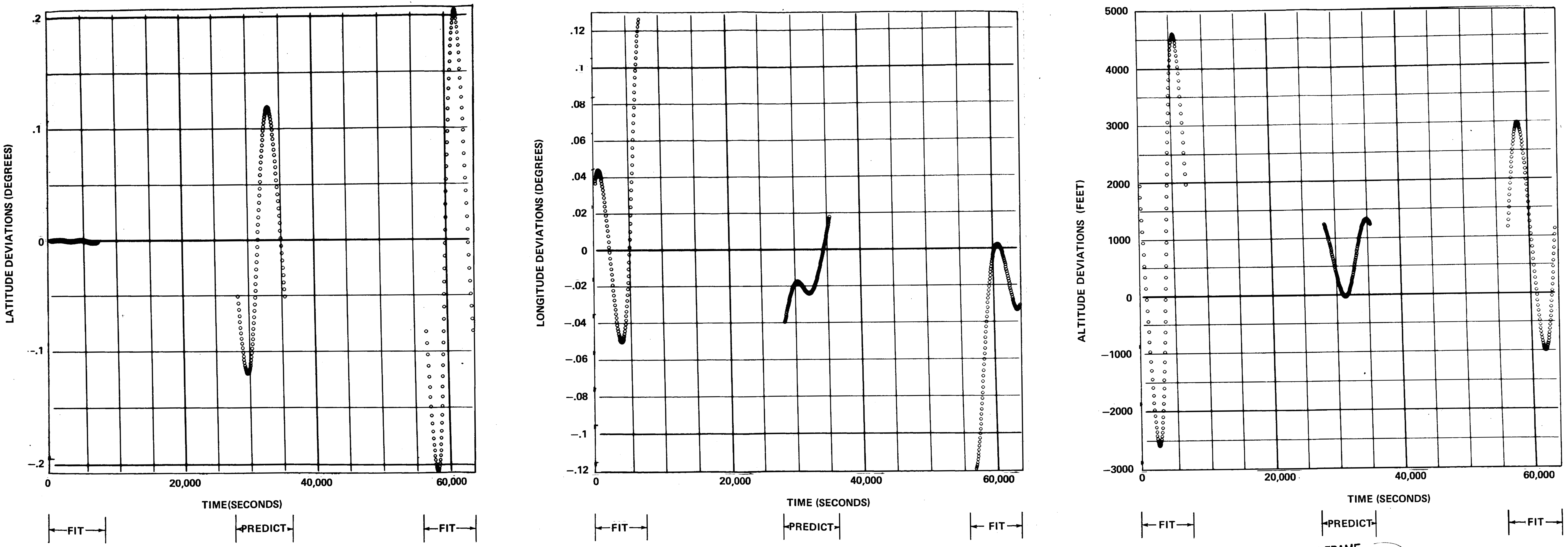
FOLDOUT FRAME 1

FIGURE 4a - POSITION DEVIATIONS FOR TWO STATION – ONE PASS SOLUTION USING LI FIELD

FOLDOUT FRAME

FOLDOUT FRAME 2

FOLDOUT FRAME 3



FOLDOUT FRAME 1

FIGURE 4b - POSITION DEVIATIONSFOR TWO STATION – TWO PASS CONSTRAINED PLANE SOLUTION USING LI FIELD

FOLDOUT FRAME 2

FOLDOUT FRAME 3

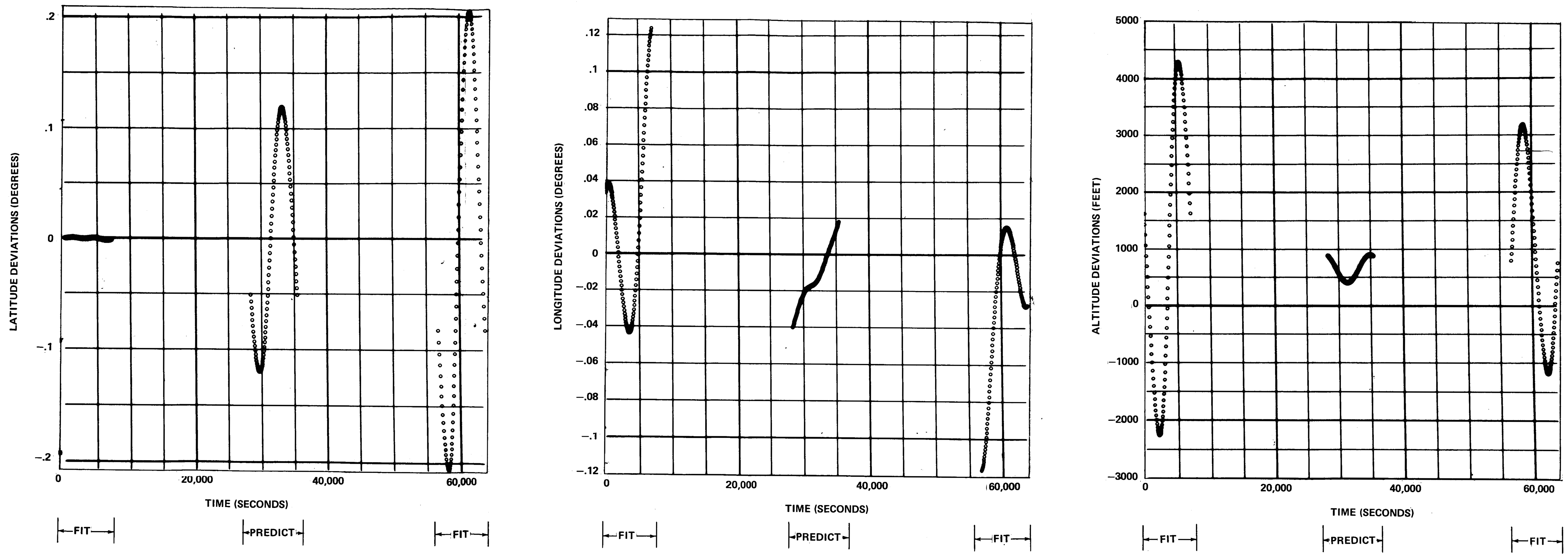


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FIGURE 4c - POSITION DEVIATIONS FOR THREE STATION – TWO PASS CONSTRAINED PLANE SOLUTION USING LI FIELD

FOLDOUT FRAME 2

FOLDOUT FRAME 3

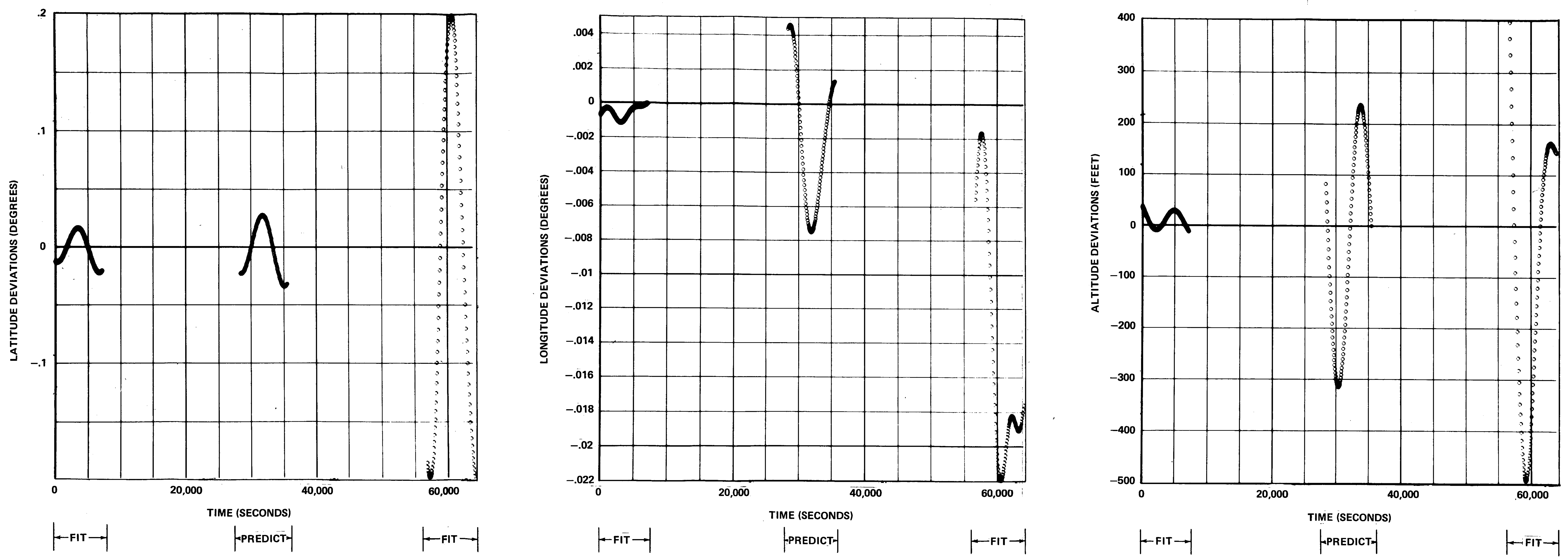
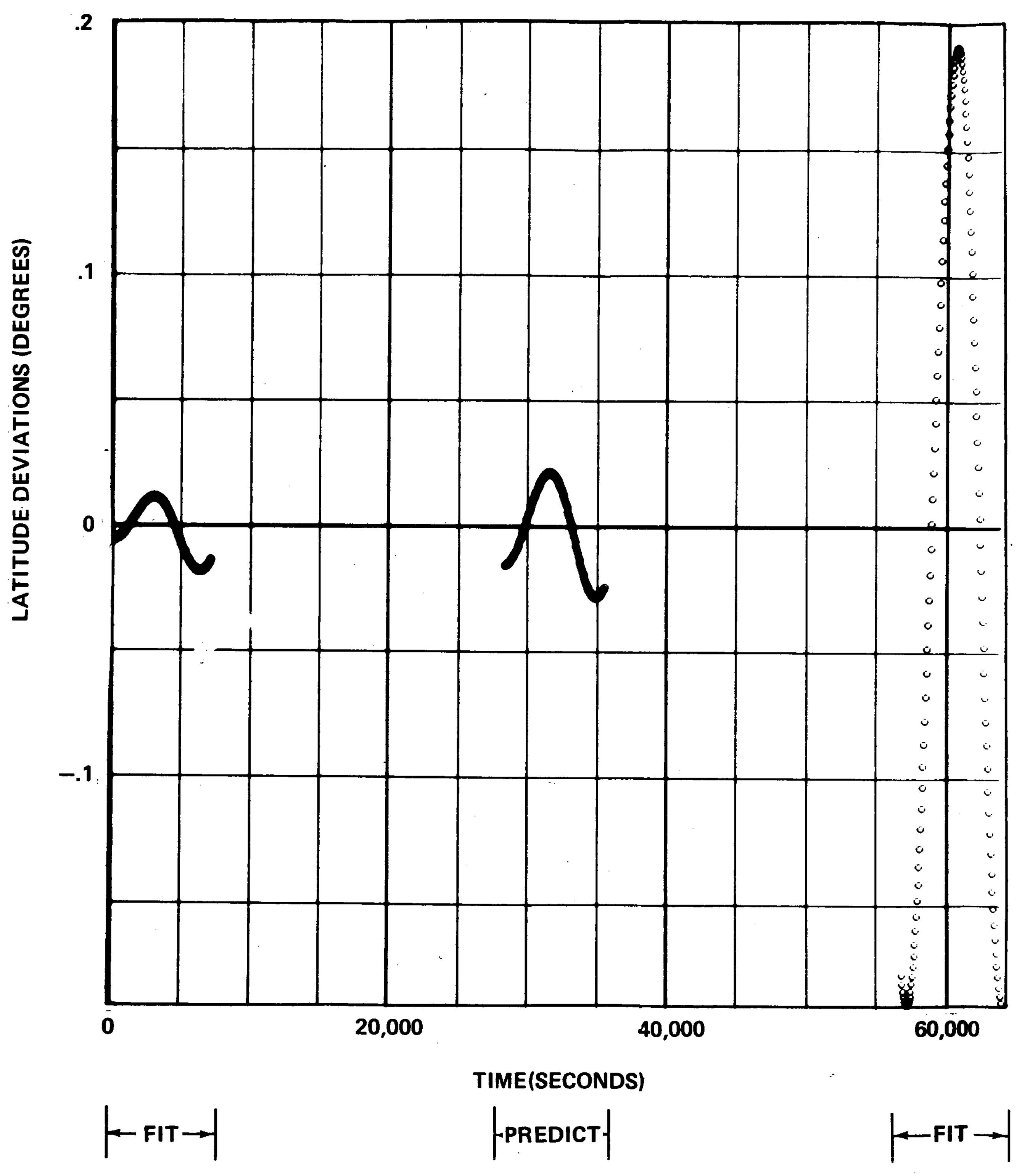


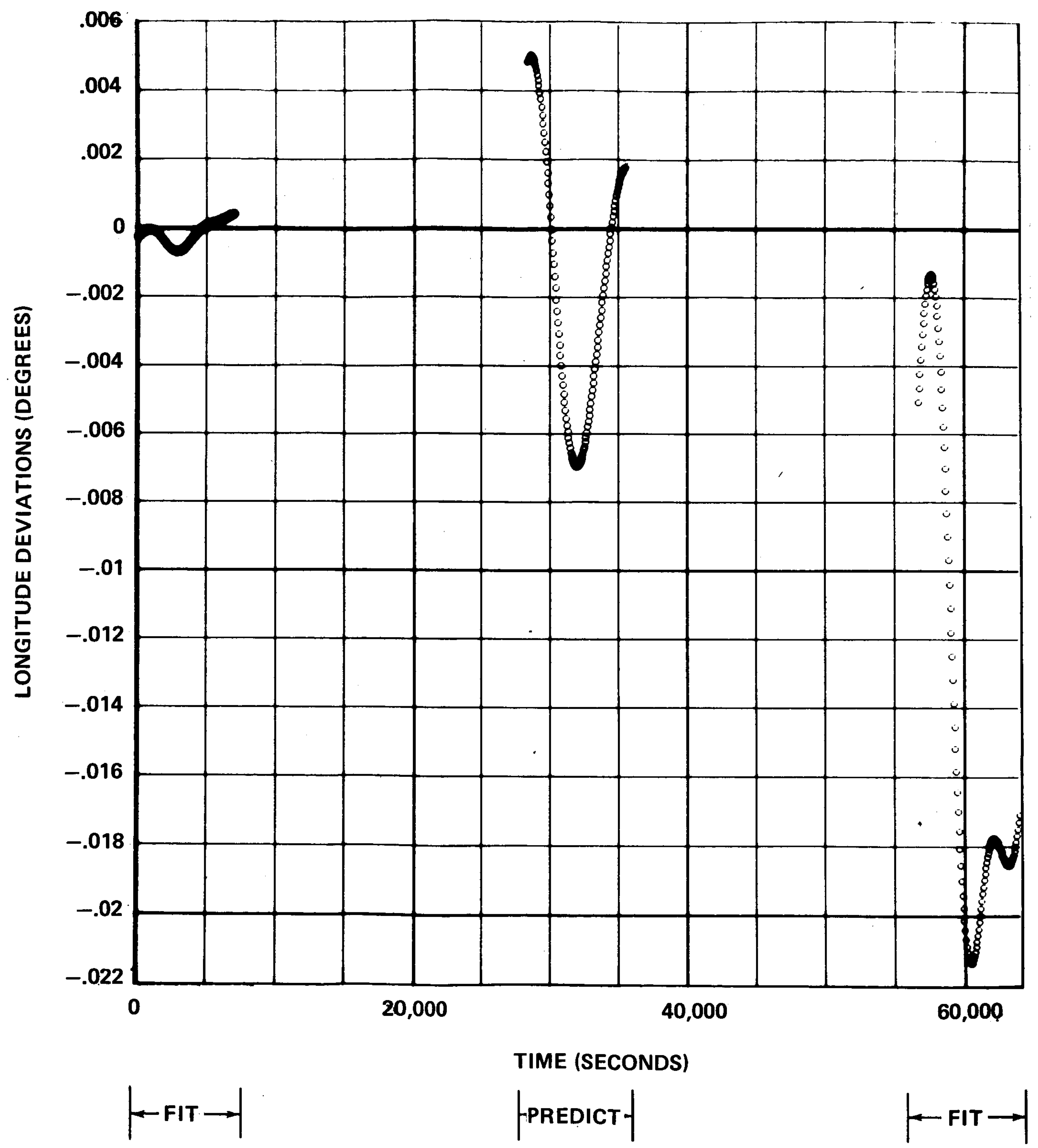
FIGURE 5a - OLEP POSITION DEVIATIONS

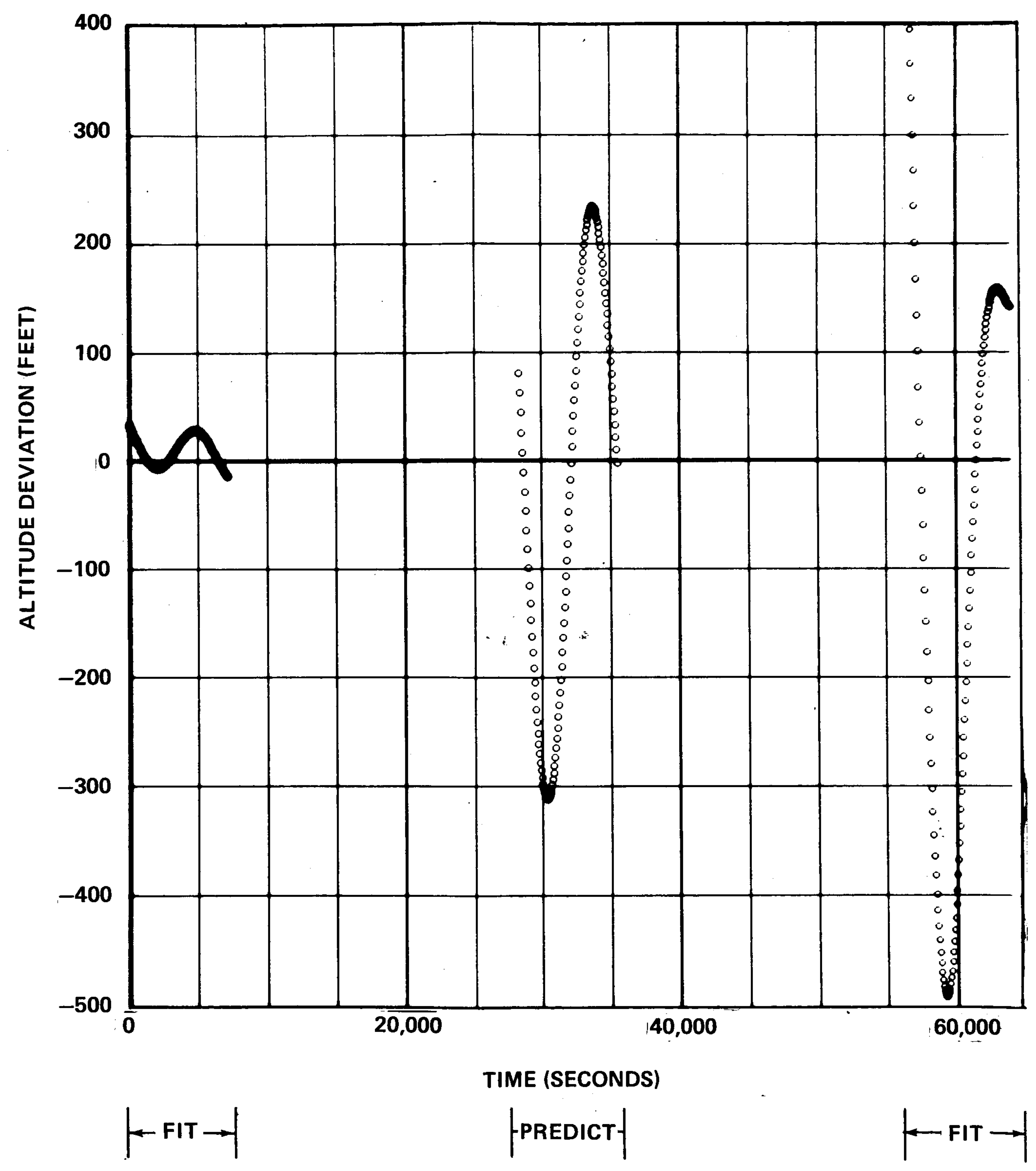
FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 3







FOLDOUT FRAME 3

FIGURE 5b - OLEP POSITION DEVIATIONS FROM CONSTRAINED INCLINATION SOLUTION

FOLDOUT FRAME 1

FOLDOUT FRAME 2

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From: M. V. Bullock, A. J. Ferrari

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